XIII STICS Seminar STICS - 13-16 November 2023 - Latresne (33)

Conceptualization, formalisms and first evaluations of a phosphorus module for the STICS soil-crop model

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Context

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First issue : Few models accounts for phosphorus cycle

→ Need to **develop crop models integrating the phosphorus cycle**

Second issue : Most modelling works focus on simulating the P in the soil

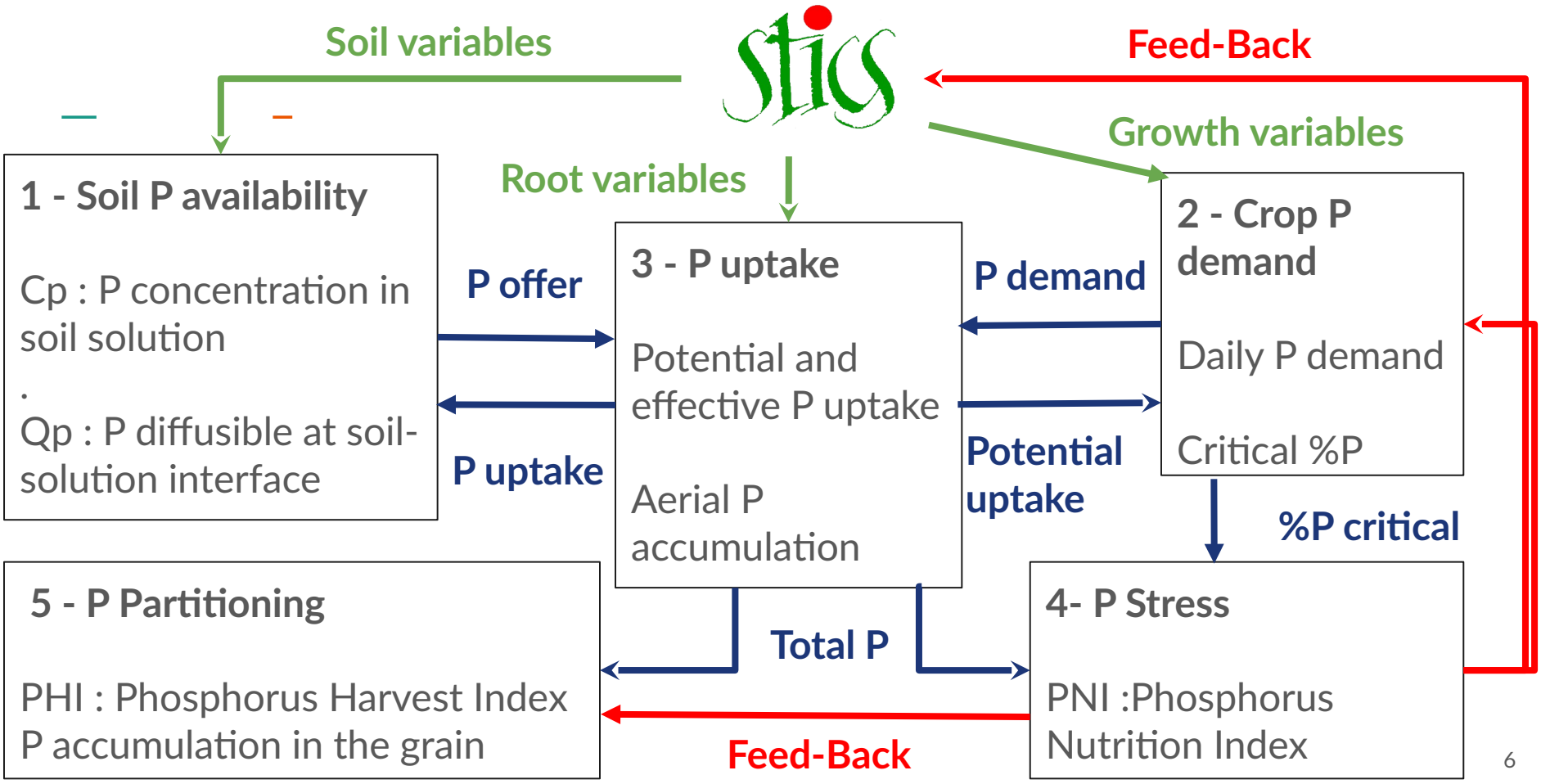
→ Need to **correctly simulate crop response to soil P availability.**

Third issue : Most modelling works focus on simulating one element at a time

→ Need for models to **handles multiple stresses effect.**

Model description

Model Summary



Module 1 : Soil P availability

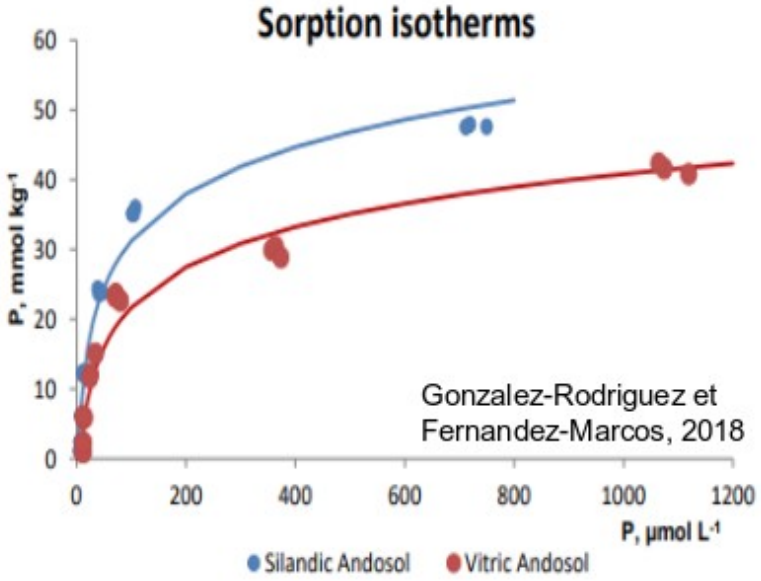
2 variables are computed :

- **P concentration in soil solution Cp** (mg / mL)

- **Buffering Power (Pr, mg/cm3)** :
  → Equilibrium Cp - Solid Phase P described by a **Freundlich equation** (t = 24h)

$$P_r = v C_p^w t^p$$

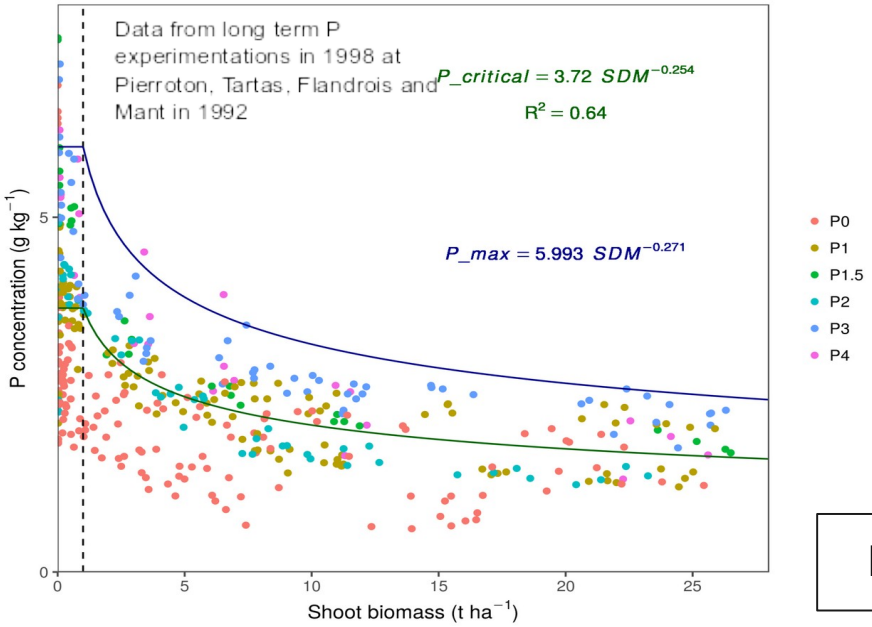
Morel et al., 2000



Does not account for organic P **(Raguet et al., 2023)**

Does not account for rhizospheric processes e.g (Mycorhizae, Citrates, Phosphatases...)

Module 2 : Plant P demand



P dilution is observed in maize crops from a threshold of 1t ha-1

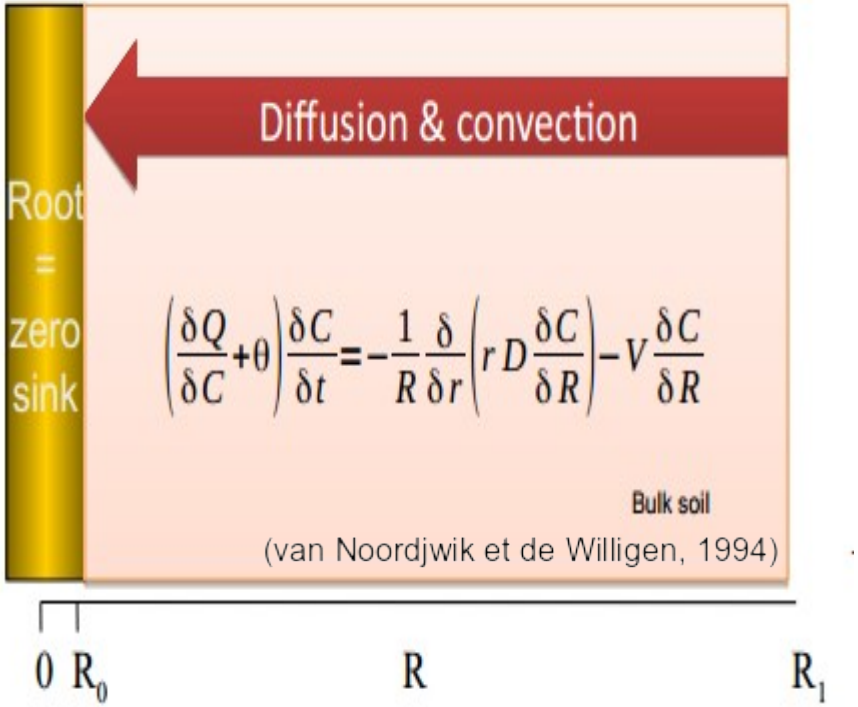
Dilution Curves : %P = a x W^{-b}

Critical dilution curve (Optimum) → Below which the crop is deficient in P → Compute demand

Demand = $(\Delta Biomass \times a_{crit} \times (1-b_{crit}) \times Biomass^{-bcrit})$

Additional root demand => fixed root concentration parameter x Δroot_biomass

Module 3 : Phosphorus Uptake



Uptake is computed for each 1cm layer

Each layer is characterized by :

- Root Length density
- Soil Property

Roots are characterized by :

- Root radius (parameter)
- Mid-distance between roots (computed)

Effective P Uptake

2 Cases :

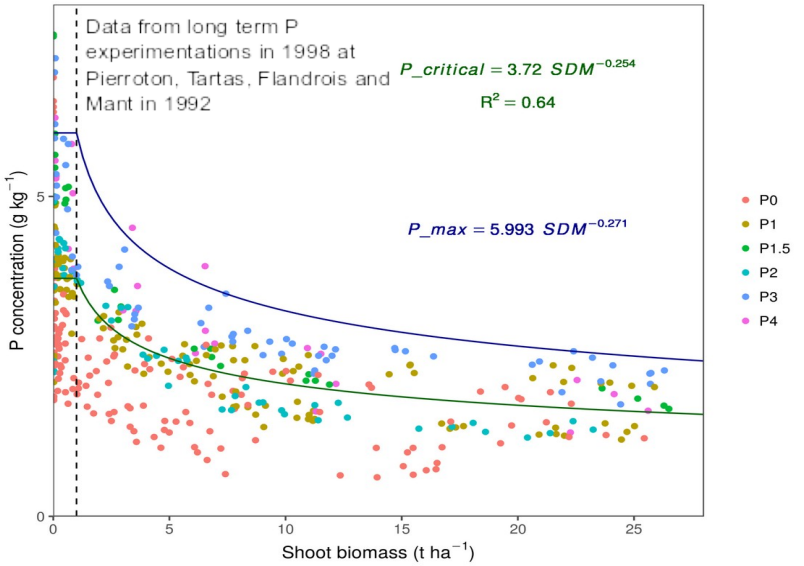
- **Case 1** : Potential Uptake < Demand ⇒ **P Shortage** ⇒ **Feed-back on growth and development**
- **Case 2** : Potential Uptake > Demand ⇒ **Need to account for uptake over critical curve**

$$\text{Demand} = \text{Demand} \times \frac{\text{Potential Uptake - Demand}}{\text{Phosphorus Nutrition Index}}$$

Demand cannot exceed **maximum accumulation curve**

$$\text{Demand\_max} = (\Delta\text{Biomass} \times a_{max} \times (1-b_{max}) \times \text{Biomass}^{-bmax})$$

If (Demand > Demand_max) → Demand = Demand_max

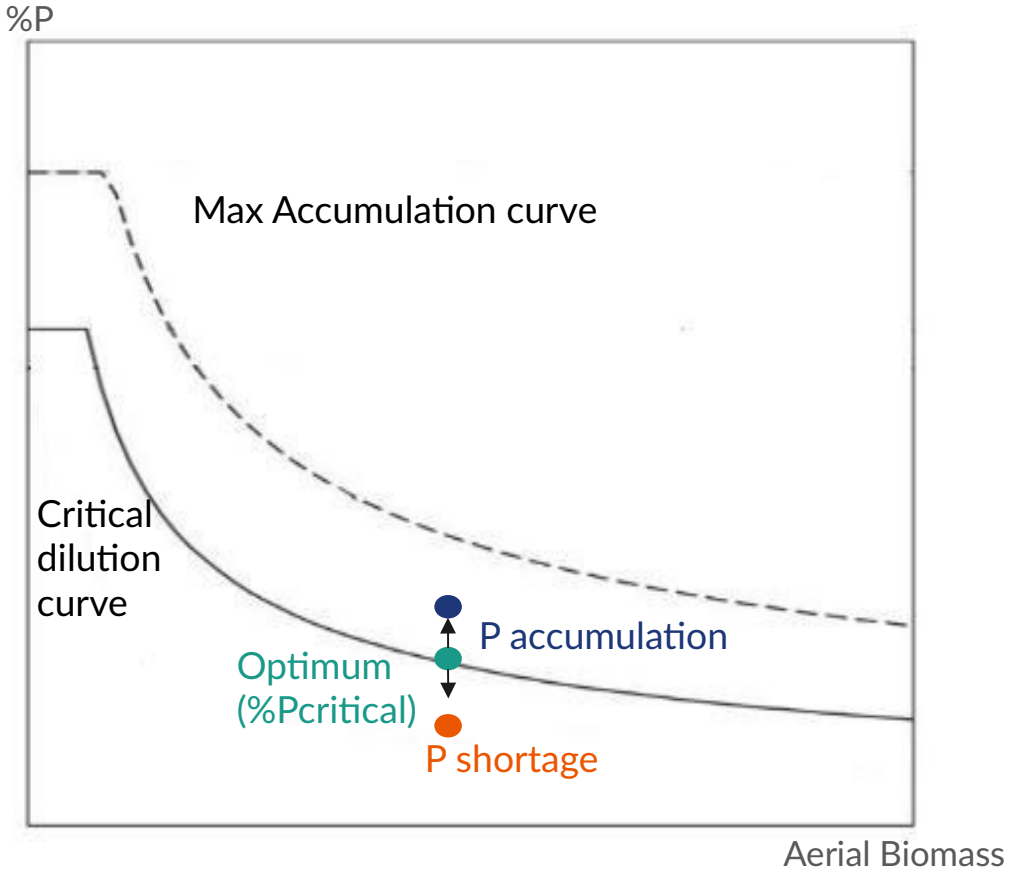


Module 4 : Phosphorus nutrition index (PNI)

PNI is calculated on the basis of current %P and %P from critical dilution curve.

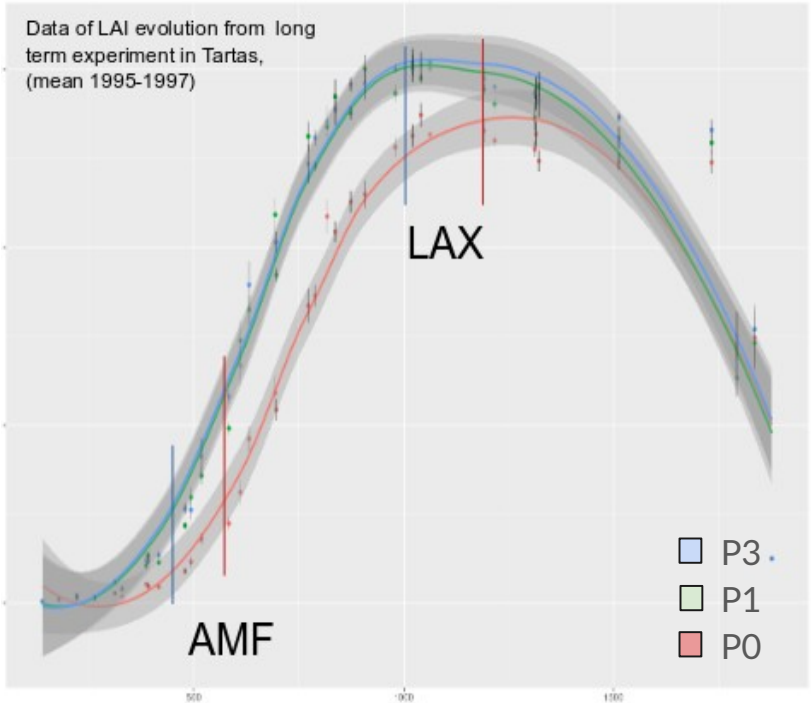
$$PNI = \frac{(\%P / \%Pcritical)}{threshold}$$

threshold parameter is a scaling factor that allows to account for crop sensitivity to P deficiency



Phosphorus deficiency feedback

LAI



Degree.days

AMF = Maximum growth rate of LAI
LAX = Maximum LAI value stage

Simulated effect :

1) **Delay on developpement :**

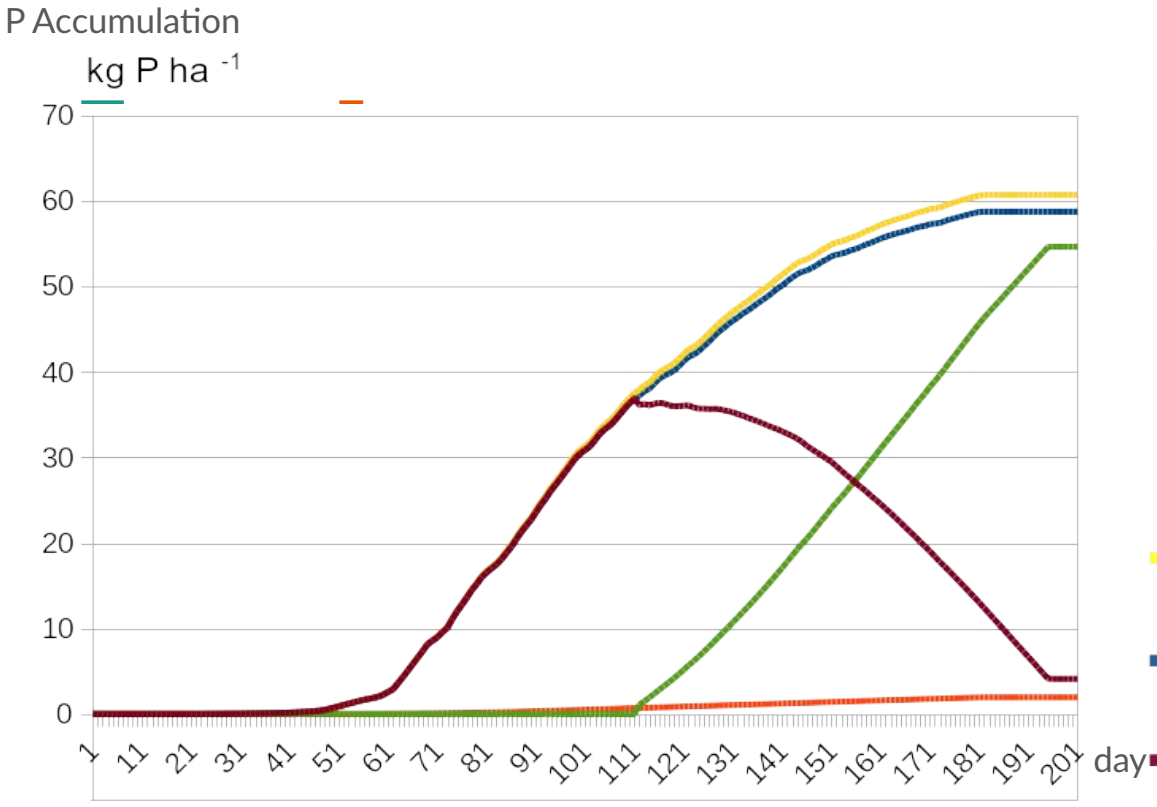
STICS reproduce development through a sum of development unit UPVT (based on degree.days UDEV).

We reduce UPVT proportionally to P shortage

2) **Increase in leaf senescence :**

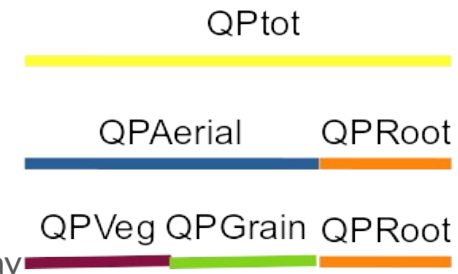
Through a reduction of leaf lifespan proportional to P shortage.

Module 5 : Phosphorus Partitioning



Evolution of P accumulation in plant parts across one cropping season

Grain P allocation => linear regression of P Harvest Index ~ degree days (analogous to N allocation)



Model evaluation

Dataset

Long-term Phosphorus fertilization trial in South-Western France (Tartas) (1972-2004)

Crop : Maize (Irrigated and Sufficient N inputs)

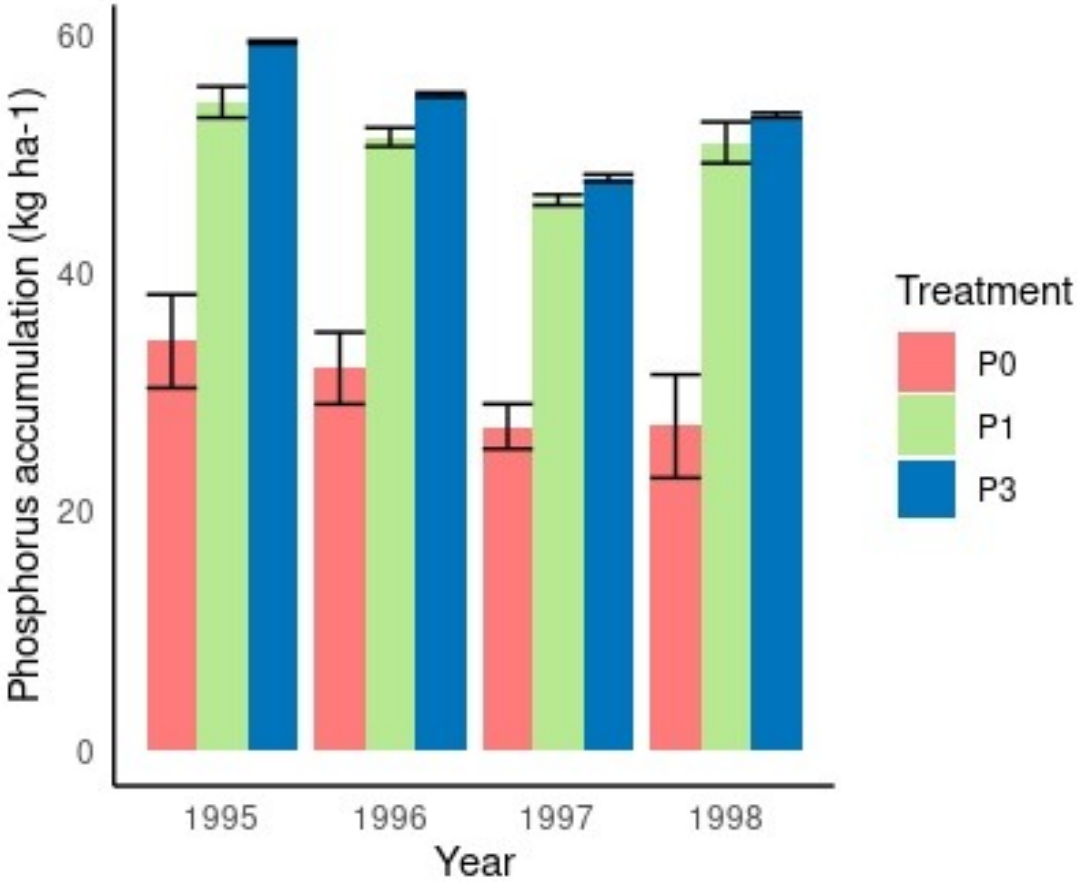
Evaluated Years : 1995-1998

Treatments : P0 - P1.5 - P3

Cultivars : Volga (1995-1997), Cecillia (1998)

Variables : Yield, Dry Biomass, Leaf Area Index, Accumulated P and N in aerial parts and in grain

Model Behaviour : P uptake

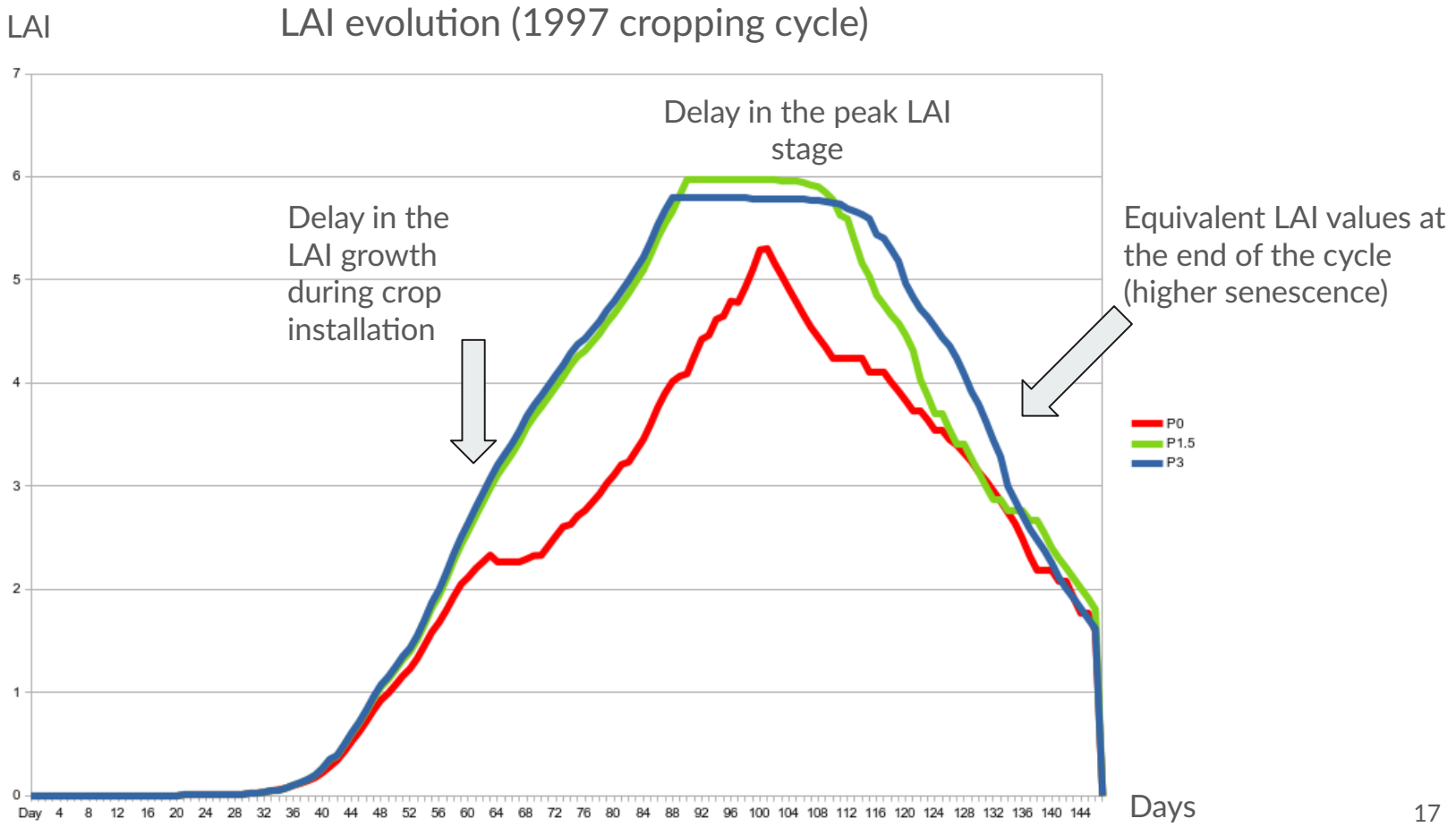


Very contrasted simulated P uptake between treatments.

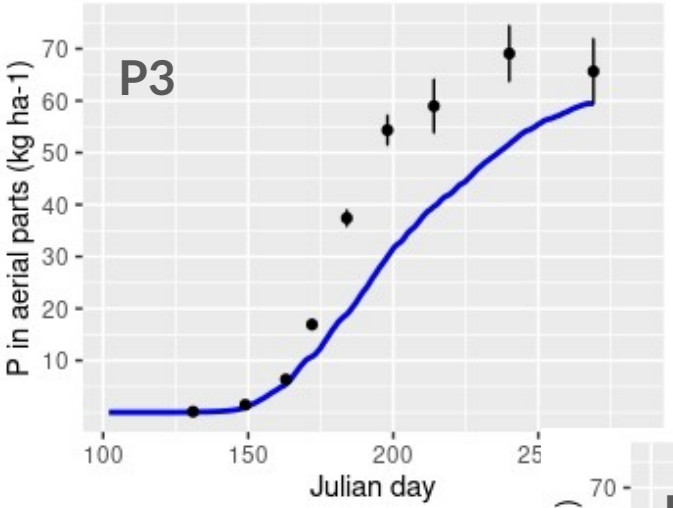
Only initial P concentration in soil solution (Cp) that varies between treatments.

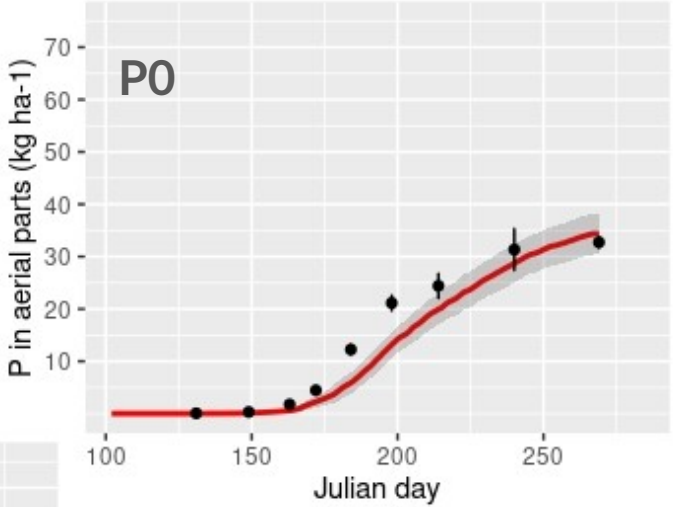
Greater variability due to Cp at low concentration.

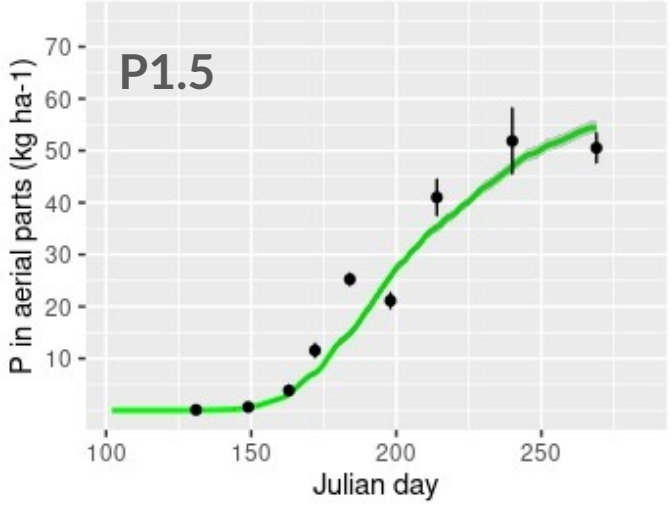
Model Behaviour : Feedbacks



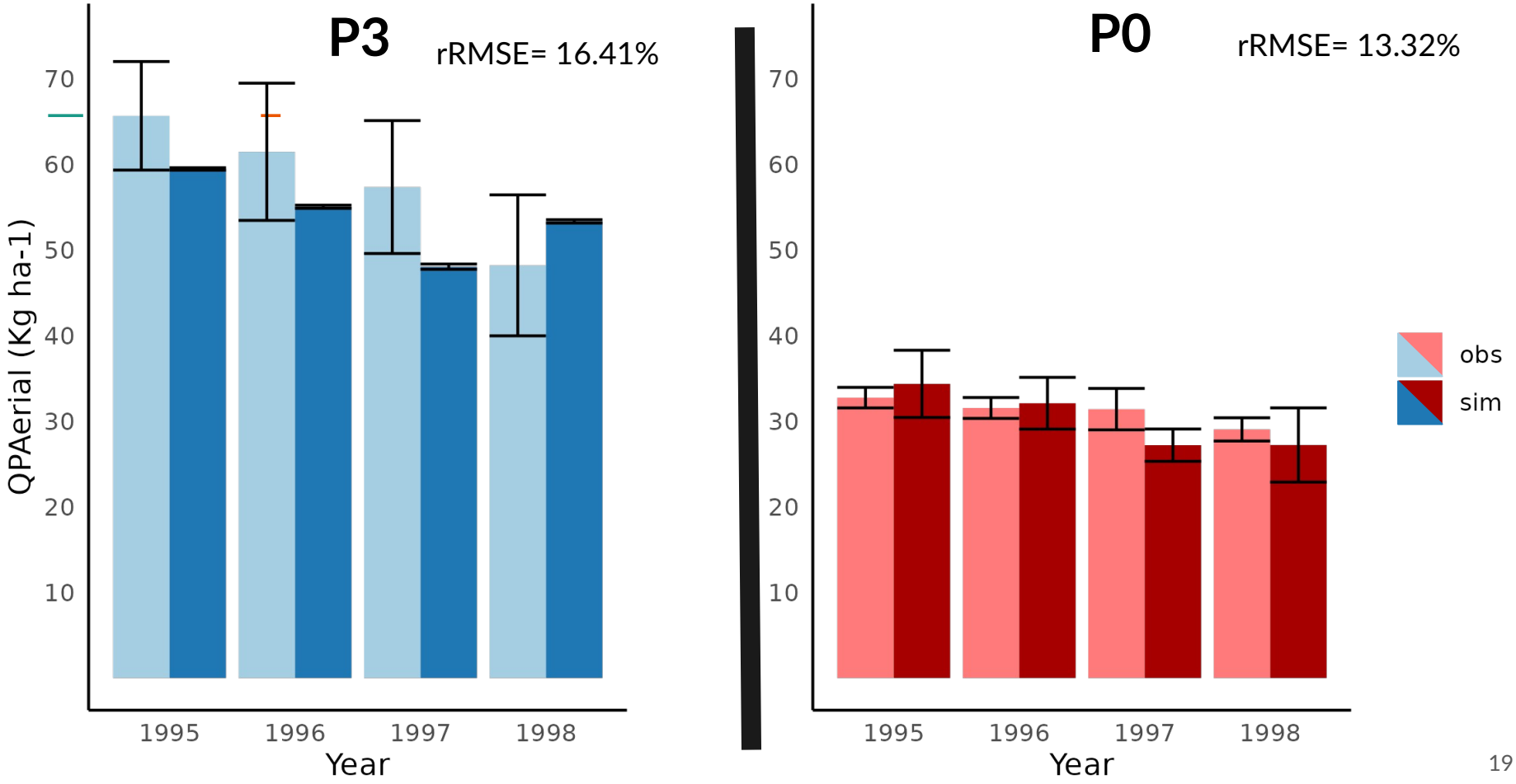
Evaluation : P accumulation dynamic (Year : 1995)







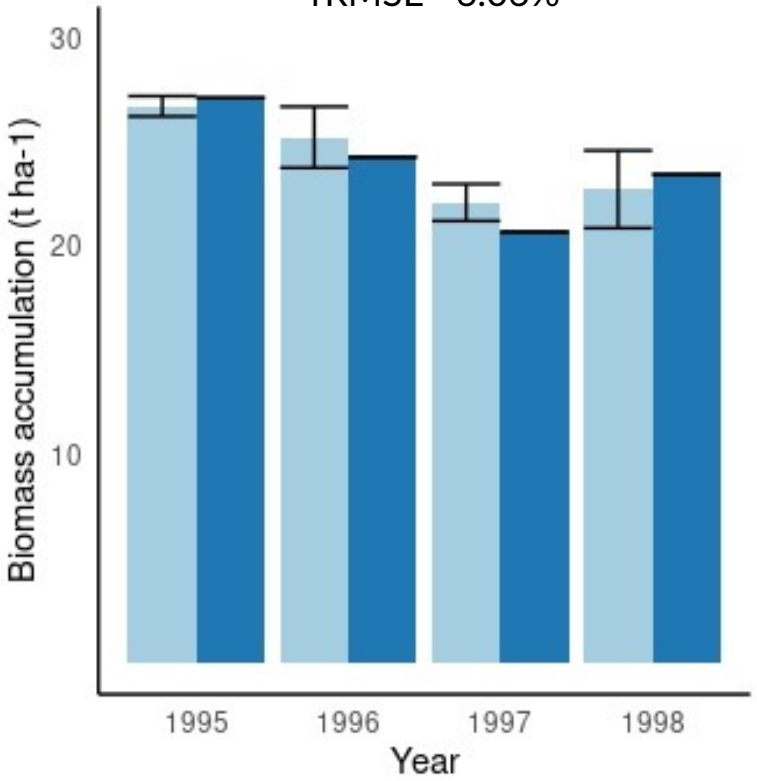
Evaluation : Simulation of P uptake (end cycle)



Evaluation : Simulation of biomass

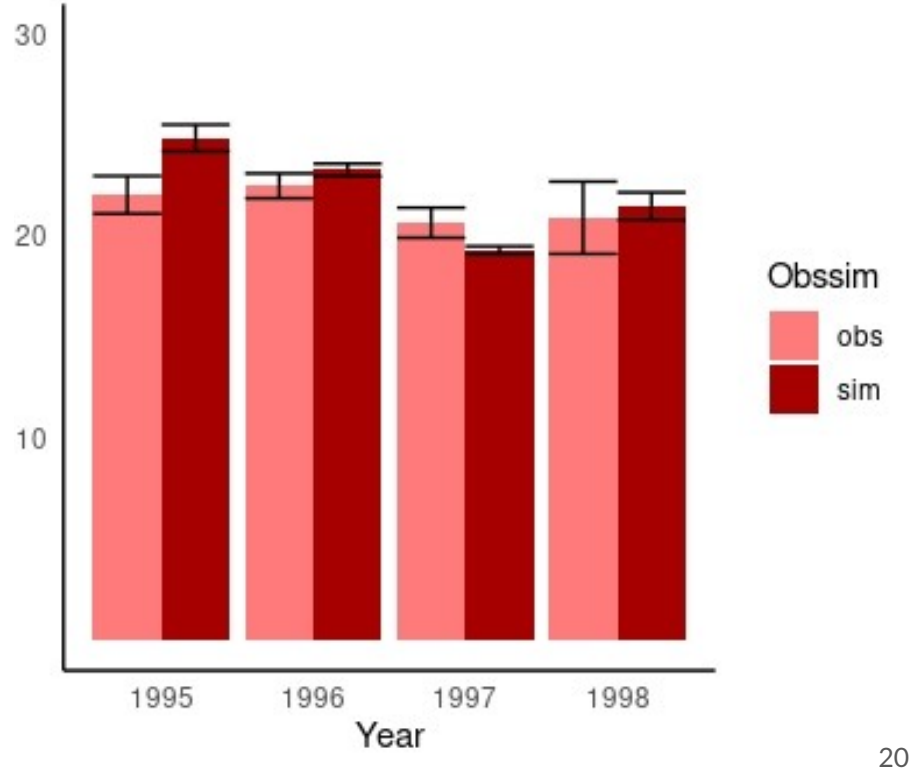
P3

rRMSE= 6.06%



P0

rRMSE= 9.35%



Conclusion and perspectives

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Model able to reproduce main P effects : Developpement delay, LAI reduction and shoot:root ratio variations.

Promising first simulations : Catch the dynamic of P accumulation as well as final plant P content and biomass.

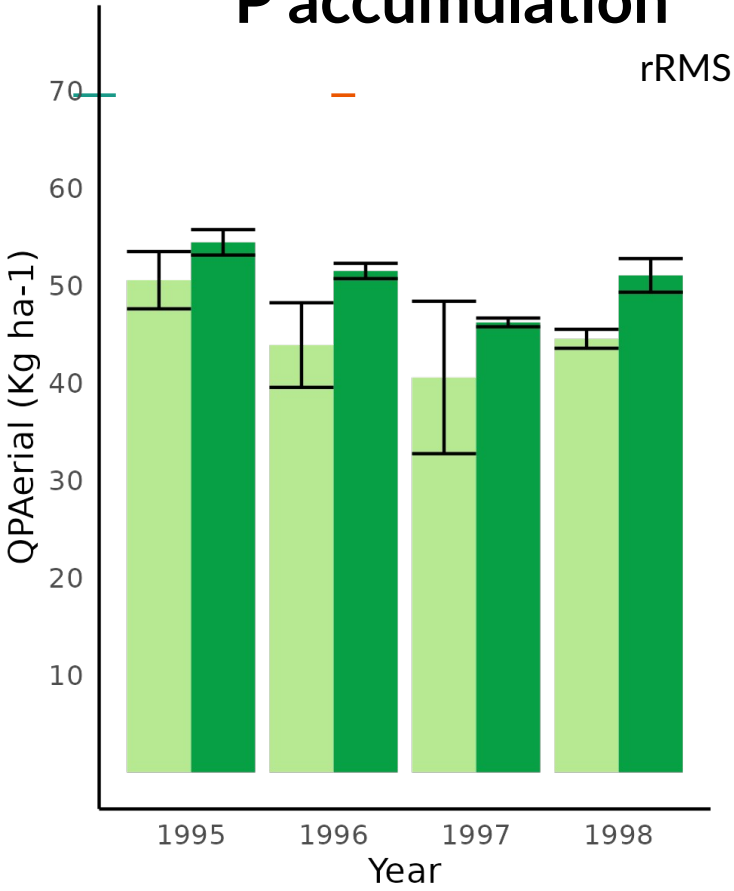
Need to test the model on contrasted pedoclimatic conditions and different species. In order to **validate the model and test the model robustness and genericity**.

Thank you for your attention

Supplementary 1 - P1.5 final P content and biomass

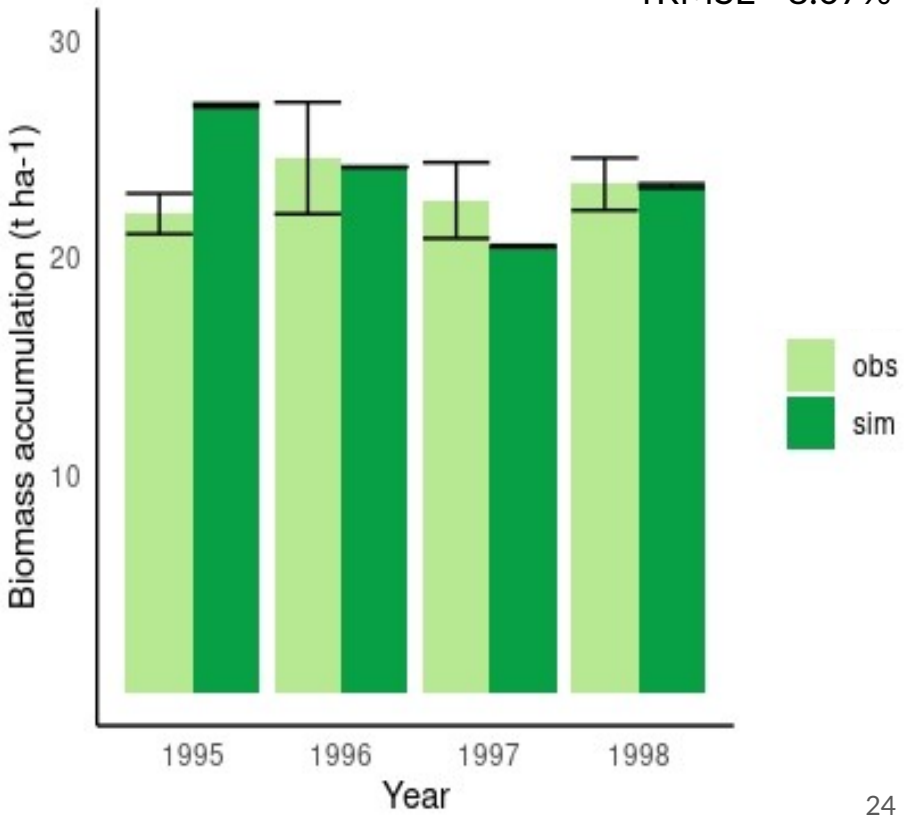
P accumulation

rRMSE= 16.4%

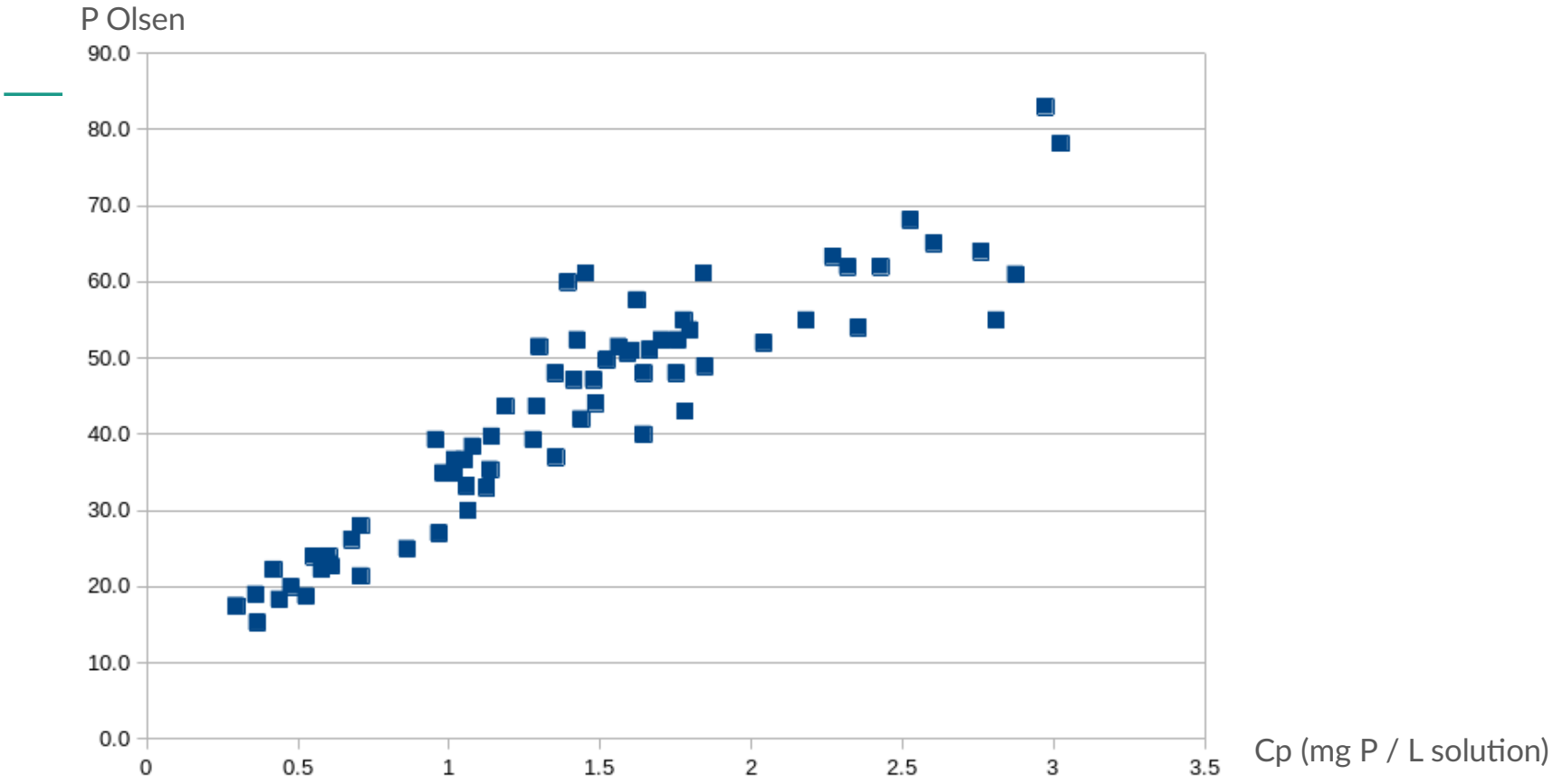


Dry biomass

rRMSE= 8.07%



Supplementary 2 - P-Olsen - Cp relation



Supplementary 3 - Shoot:Root ratio variations